Abstract

There is an ever increasing demand for higher spectral usage in wireless communication, radar and imaging systems. Higher spectral efficiency can be achieved using components that are aware of system environment and adapt suitably to the operating conditions. In this regard, radio frequency (RF) signal analysis is of paramount interest. Emergence of dispersive delay networks (DDN) has led to the significant development of microwave analog-signal processing (ASP) and analysis. DDN causes displacement of spectral components in time domain, relative to the frequency dependant group delay response. The main challenge in the design of DDN in this context is in achieving broad bandwidth with high group delay dispersion (GDD). In this regard, all-pass networks (APN) have been explored as a potential wide-band DDN owing to the possibility of controlling the magnitude of loss characteristics without affecting the dispersion in group delay response. The synthesis procedure of lumped element APN using approximation methods is well known at audio frequencies. Most of these use operational amplifier and cannot be extended directly to RF. There is no generalised closed form analytical procedure at RF for the synthesis of APN with the required GDD. In this regard, this dissertation presents the design and implementation of all-pass networks as wide-band dispersive delay networks at radio frequencies.

In this work, we begin by analysing the signal propagation through a DDN with a linear group delay response over a broad bandwidth. It is found that the signal experiences expansion of pulse width, reduction of its peak amplitude and a temporal displacement of the spectral components. Analytical expressions derived help initial synthesis of group delay response required for various ASP applications.

As the first step towards implementation at RF, a single stage APN is designed using surface mount devices (SMD). This design approach takes into account practical issues such as parasitics due to mounting pads, available component values, physical dimensions, self resonance frequency (SRF) and finite Q factor of the components used. Full wave simulation of the design with transmission line pads and components is carried out. This implementation is useful for frequencies up to the component SRF, generally about 5

GHz. This design approach makes the circuit footprint independent of frequency and the performance is limited only by the Q factor of the adopted technology. The Q factor affects the loss characteristics with a negligible effect on group delay response in the frequency band of interest.

In order to extend the APN design for high group delay, a novel board level implementation is developed consisting of both lumped SMD components and distributed elements. The implementation results in a lower sensitivity of group delay performance to the commercially specified component value tolerances than the approach using all SMD components. It has been experimentally verified that the measured group delay is 2.4 ns at 1.85 GHz, which is thrice that reported in other approaches. The implementation has a reduced circuit footprint and is attractive in practical applications as it is a single layer microstrip realisation with less complex fabrication procedure and fewer components to assemble.

As an extension of this towards wideband cascaded APN, an iterative design procedure is developed to achieve a monotonous group delay response over a broad bandwidth. The approach facilitates cascading of multiple stages of lumped APN with different resonance frequency and peak group delay to obtain linear and non-linear group delay responses with both positive and negative GDD. Circuits with both positive and negative GDD are required for various ASP applications such as compressive receivers and the present approach is unique in obtaining both the responses, not possible with many other RF dispersion techniques. Circuit models have been simulated by cascading transfer function responses of the individual APNs. The design is further extended for SMD implementation.

To validate the above approach, a two stage APN is designed in the frequency range [0.5 - 1] GHz for a linear GDD of ± 6 ns/GHz. Two negative GDD APNs are further cascaded to obtain a four stage implementation with an overall GDD of -12 ns/GHz. The experimental results are compared with full wave simulations for validation. The design using lumped SMD components has greatly improved the performance in terms of GDD with a reduced circuit footprint and lower insertion loss than previously reported approaches.

As practical examples, the ASP modules are experimentally demonstrated using the fabricated APN. Frequency discrimination of two input frequencies with a frequency resolution of 500 MHz is demonstrated. Higher GDD results in higher separation of frequency components in time domain. Pulse compression and magnification is also demonstrated for different wideband LFM input signals. The dispersion effects of amplitude reduction, pulse width expansion and frequency chirping are thereby validated experimentally.

In summary, the approaches presented in this dissertation enable the design of wideband all-pass networks to introduce dispersion delays over wide bandwidths, opening up the possibility for their use in analog signal processing at radio frequencies. Some of these applications have been experimentally demonstrated and validated using time frequency analysis.